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EFFECTS OF TERRIGENOUS SEDIMENT INFLUX ON CORAL REEF ZONATION IN SOUTHWESTERN PUERTO RICO

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ABSTRACT

The distribution of hermatypic coral species and species dominance patterns is discussed from the study of eight reef sites off southwestern Puerto Rico. Photo-transects were surveyed on four sites at La Parguera where terrigenous sediment influx was absent and used to develop a standard coral zonation pattern. Four sites were studied at Ponce where the presence of terrigenous sediments was observed and results compared between sites for each depth level.

Coral cover and species diversity was greatly reduced near the source of terrigenous sediment. Both coral cover and coral species diversity increased with distance from the sediment source.

Loss of light is critical to the deeper coral assemblages, and a chronic increase in turbidity will move the lower limit of coral growth to much shallower depths. Other possible effects from sediment influx commonly observed were: partial or total burial of coral colonies, bleaching and colonization of the coral surface by filamentous blue-green algae.

INTRODUCTION

Despite the widespread attention that coral reefs have received, most studies have been qualitative, focusing on describing the distribution of coral species. More detail is necessary in order to understand species dominance, distribution with depth, stress, and community interactions.

Coral reefs are a significant resource which are threatened by many man-made and natural influences, including increasing turbidity and siltation, abnormal inputs of nutrients and organic matter, pollution by toxic chemicals, thermal loading changes in water circulation and wave exposure, direct physical damage and breakage, and the selective removal of organisms.

Puerto Rico's offshore reefs are still in good condition, but the environment of much of the nearshore regions of all coast have changed to a high terrigenous sediment influx condition with a loss of coral cover accompanied by lack of corals growth or recolonization of reefs areas. Eight reef sites were surveyed to analyze the reef front zonation and changes that occur with changes in sediment influx (Figure 1).

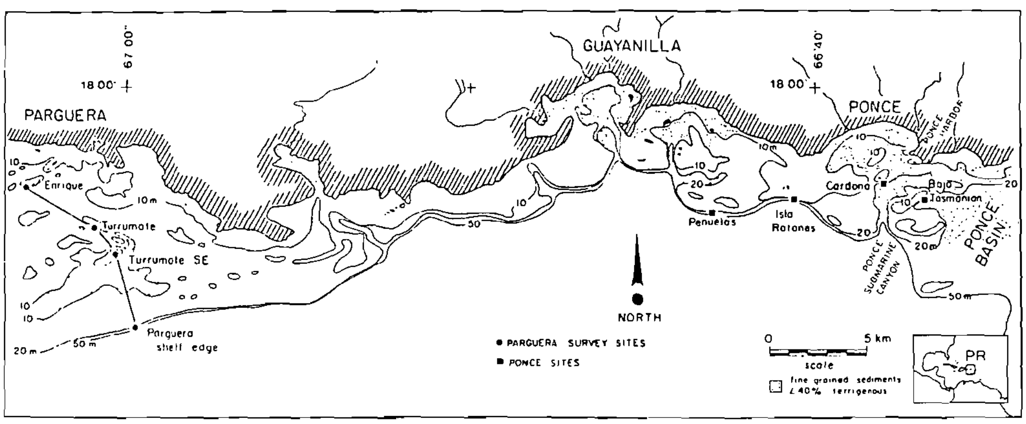


Figure 1. Location map of reef study sites, Southwest Puerto Rico.

METHODS

We used a technique of photographic transects and measurement from the photos which provides enough data to quantify the percent cover by different coral species and the diversity of species with changes in depth and changes with influx of external terrigenous sediments.

Three 15 meters chains were surveyed at each 5 meter depth interval down the reef front. Eleven photographs of 70 x 100 cm each were taken along each chain. The three chains were tested to detect significant differences and then pooled. Corals were identified in the field and tagged for recognition on the photographs.

Each photograph was analyzed by outlining coral colonies and identifying its species according to the number tag visible on the photograph. Areas of living coral were measured with a compensating polar planimeter and the results recorded for each species. Total coral cover and cover by species were recorded relative to the total area of the photgraph.

An ANOVA test developed by Link & Wallace (1952) was performed on coral cover results in order to detect significant differences in species distributions with depth and between study sites. A five percent confidence limit was picked to keep the rejection of a null hypothesis or type I error at a safe level.

Sediment was collected from reef pockets and sediment drainage channels at all survey sites and depth levels. These were analyzed for grain size and percent of terrigenous (acid-insoluble) components.

SOUTHWESTERN PUERTO RICO REEF FRONT ZONATION

Five distinct coral reef zones can be distinguished below the reef crest (Figure 2). The community zonation of the reef front is similar to that at Yucatan (Logan 1969), Jamaica (Goreau & Goreau 1973), and Belize (James & Ginsburg 1979). Zonation boundaries cannot be determined by community structure alone, the morphology of the bottom, growth forms of the colonies, and other factors that influence the pattern of the reef also determines the reef zones.

The *Acropora palmata* zone is restricted to relatively clear waters with moderate to strong wave energy. It is dominated by *Acropora palmata* but may also have abundant *Montastrea annularis, Diploria* species, and other small massive corals. The branches of *Acropora palmata* may be oriented to the incoming waves, but the spur-and-groove development typical of Florida reefs is absent in Puerto Rico. This zone is absent or poorly developed on inshore mangrove islets at Parguera, and on the silted reefs off Guánica, Guayanilla, and Ponce. It is frequently modified by hurricane waves and the area may be reduced to in situ rubble or debris transported into the supralittoral reef.

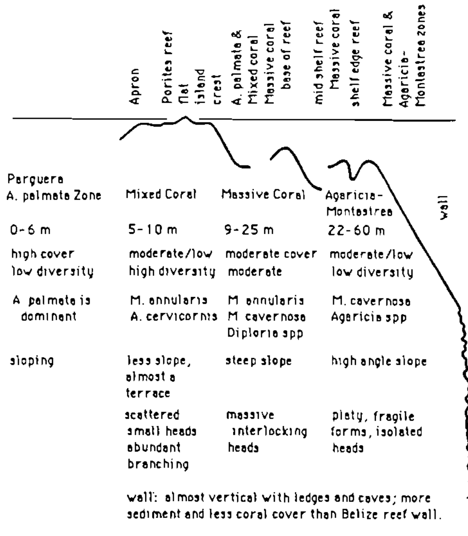


Figure 2. Southwest Puerto Rico Coral Reef Front Zonation (Modified from Morelock 1986).

The Mixed Coral Zone is dominated by *Montastrea annularis* and *Acropora cervicornis*. This zone occupies a fairly level part of the reef front, and is distinguishable mainly because of the effects of a change from steeper slopes found in the other zones. Abundant octocoral and numerous marine invertebrates are associated with this zone and, in places, the assemblage approaches a hardground facies.

A break in slope generally occurs between the Mixed Coral Zone and the Massive Coral Zone. Coral species in the massive zone grow on a relatively steep slope and are dominated by *Montastrea, Porites*, and *Agaricia* species (Table 1). At Parguera the upper part of the zone terminates at 12 to 14 meters on the emergent reefs. The lower part of the massive zone was measured at the submerged reef southeast of Turrumote reef and at the submerged shelf edge reef. At Peñuelas, the section was continuous from 15 meters.

The composition of the reef community on the insular slope changes at 22 to 24 meters water depth, and the *Montastrea-Agaricia* coral zone can be distinguished. This zone was described at Alacran reef, Mexico (Logan 1969), and in Puerto Rico by Morelock et al. (1979) and Boulon (1979). *Agaricia* species and *Montastrea annularis* dominate this zone. Colony morphology changes to the platy forms.

Dives to 75 meters off Parguera and Mayaguez have shown no reef wall as described at Belize, Jamaica, and the Bahamas (James & Ginsburg, 1979), but a wall very similar to the Belize wall was observed and photographed during a submersible dive by fisheries biologists from the University of Puerto Rico south of Guánica Bay. The wall began at 85 meters, and ends at 210 meters where it was covered by a forereef sediment accumulation. The description of this wall is very similar to the Belize reef wall.

Table 1. Total Coral Cover by Species at Parguera and Peñuelas.

location	depth	%tot.cov.	sps	Mna	Mnc	Aga	Agl	Pra	Sds	Mem	Cln	Dps	Dpc	Dpl	Stm	Mad	Myf	Myl	Acc
Parguera shelf edge	20	43.2	21	24.0	3.0	7.0		3.0	.8	1.0	2.0	.7	t	.6	.2	1	.2	.2	
Parguera shelf edge	25	49.0	8	26.0	2.2	15.2	1	3.0	.4	7	t	t	1	.4	1	1	.3	.2	
Parguera shelf edge	30	40.7	19	14.7	2.7	14.0	4.4	2.0	.2	.3		.4	.2	.3	.1	.2	.3	.2	
Turrumote SE	15	15.7	13	6.5	2.4	2.0		1.0	1.1	.4	1.0	1	1	7				1	.1
Turrumote SE	20	20.8	14	4.9	8.0	3.5		1.5	1.0	.6	.4	.2		.5	.1	1		1	.2
Turrumote	5	6.8	8	.5				2.2	.3			.8	t		t				.6
Turrumote	10	21.7	18	9.9	2.2	2.1		.4	1.6	1	2.2	t			.2	.1		.3	1.8
Enrique	5	25.0	12	18.0	t	7		.4	.6		1.4							.2	1
Enrique	10	24.1	16	3.9	1.3	9.5		.7	1.4	1	2.0				1	1		1	4.6
Peñuelas	IS	28.7	17	16.0	2.1	3.4	1	1.6	4	.3	2.3	.2			1	.2			1
Peñuelas	20	24.1	16	10.7	2.1	6.2	.4	1.4	.9	.8	.3	.2	t		.2	1		.1	
Peñuelas	25	17.7	18	2.7	1.7	8.2	.4	.6	.5	.9		.3			.9	.2		.8	
Peñuelas	30	8.1	11	i	.S	3.4	3.8		1	.1					t	.1			

Montastrea annularis	Mna
Montastrea cavernosa	Mnc
Agaricia agaricites	Aga
Agaricia lamarcki	Agl
Porites asteroides	Pra
Siderastrea siderea	Sds
Meandrina meandrites	Mem
Colpophyllia natans	Cln
Diploria strigosa	Dps
D. labrynthiformis	Dpl
Stephanocoenia mich	Stm
Madracis decactis	Mad
Mycetophyllia ferox	Myf
M. lamarckii	Myl
Acropora cervicornis	Acc

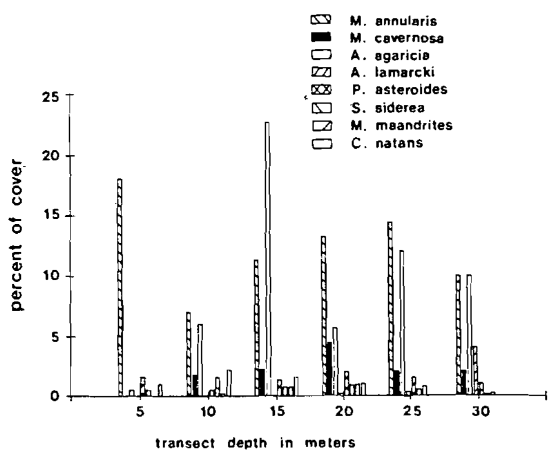
Several changes in cover by coral species occurs with depth changes on the reef front. *Montastrea annularis* is significantly higher in cover at 25 meters compared to the 30 meters level at Parguera. At Peñuelas the cover by *Montastrea annularis* is higher at 15 meters as compared to 25 and 30 meters. *Montastrea annularis* is significantly higher in abundance at 15 and 20 meters. *Agaricia agaricites* shows a significant increase at 20 meters (Figure 3).

CHANGES IN REEF FRONT ZONATION RELATED TO SEDIMENT STRESS

Reef sites survey at Ponce were Bajo Tasmanian, Cayo Cardona, and Cayo Ratones. These are affected by a point source sediment plume which is frequently formed in the Ponce Basin by wave action resuspension of bottom sediment. This plume drift west-northwest over Bajo Tasmanian and Cardona reefs, and a remnant of the plume moves less often over the Ratones reef area. A significant variation in water transparency was observed among the study sites. At Ponce, water transparency was lowest at Bajo Tasmaian and Cardona Reefs. Secchi readings average 3.5 meters. Ratones had 8 meters average Secchi. Peñuelas has 18 meters Sceehi at the shelf edge and the Parguera shelf edge readings exceeded 25 meters. Turrumote and Enrique reefs at Parguera average 15 meters Sceehi readings.

The coral cover and diversity on Bajo Tasmanian and Cayo Cardona reefs were severely modified by chronic sediment stress (Table 2). *Montastrea cavernosa* dominates the coral

Figure 3. Changes in coral species cover with depth.



cover, and the percent total coral cover is drastically reduced at each equivalent depth in relation to the other reefs. This coral is considered one of the most sediment-resistant species of the scleractinian corals (Lasker 1980; Loya 1976). The total cover of *Montastrea cavernosa* is not significantly different from values at La Parguera, but the reduction or absence of the other coral species changes the relative abundance and reinforces the conclusion the *Montastrea cavernosa* is highly tolerant to a long-term sediment stress conditions. The least

Table 2. Total coral cover by species at Ponce.

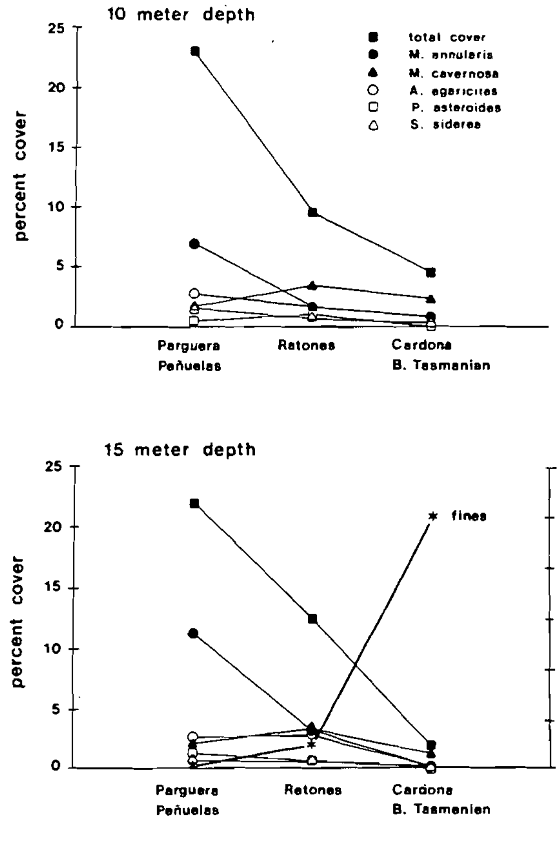
location	trans	total	n.sp	Mna	Mnc	Aga	Agl	Pra	Sds	Mem	Cln	Dps	Dpc	Dpl	Stm	Mad	Myf	Myl	Acc
B. Tasmanian	10m	5.5	13	1.5	2.0	t		t	.5	.5	t	t				t			
B. Tasmanian	15m	3.1	11	.2	1.8	.3	1	t		1					.2	t		.3	
Cardona	5m	0.4	3						t			.1							
Cardona	10m	3.6	11	.1	2.5	t		t	.1	.6		.3			t	t			
Ratones	5m	6	9	2.3	t	1		1.1	.3						.1				
Ratones	10m	9.5	14	1.6	4.1	1.6		1.0	.7	.2	t	.2	t	t	t	.2			
Ratonmes	15m	12.5	11	3.3	3.4	2.9	.5	.7	.6	.3					t	.4		.4	
Ratones	20m	6.7	13	.5	1.1	3.0	.6	t	.4	.1					t	1		t	
Ratones	25m	4.8	7			.4	3.9	1··	.2	t					.1	.1			
Ratones	30m	0.1	2				t									t			

sediment-tolerant species, *Acropora palmata*, was not present; and it is largely absent on reefs with high sediment influx (Morelock et al. 1969). A deep water coral, Agaricia lamarcki was found at 15 meters on Bajo Tasmanian, suggesting that the light levels are greatly reduced; at Cayo Cardona no living coral were found below 12 meters, and dead coral heads were covered with a sediment-algae mat.

Changes in coral cover on Cayo Ratones were less than at Cardona. Coral cover and species diversity were higher compared with Bajo Tasmanian and Cayo Cardona reefs, but deeper parts of the reef were affected by terrigenous sedimentation. Below 15 meters, the wave action on the south coast does not remove fine sediments, and the combination of depth and turbidity causes greater light reduction. *Montastrea cavernosa* was the dominant species at 10 meters depth and abundant at 15 meters. Below 15 meters a platy coral assemblage was dominant. At 25 meters only four coral species were present in appreciable amounts, with only *Agaricia lamarcki* common. The last colonies to survive in areas of high sediment were *Montastrea cavernosa, Siderastrea siderea, Agaricia agaricites,* and *Porites asteroides. Montastrea cavernosa* and *Siderastrea siderea* have been characterized as effective sediment removers by Loya (1976) and Lasker (1980). These become important elements in the coral assemblage on the sediment impacted reefs. Loya reported that water turbidity and sedimentation seemed to be the major factors that dictate the distribution of corals in different reef zones. The changes in coral cover between sites (Figure 4) shows significant decreases in the amount of cover provided by *Montastrea annularis,* and decreases in *Porites asteroides* and *Agarica agaricites* abundances.

Coral cover was reduced near the source of terrigenous sediment influx and coral cover and diversity increased with distance from the Ponce Basin. Sediments trapped on the reefs decreased with increasing distance from the Basin suggesting that the plume influx was an important factor contributing to the deterioration of these reefs. The Ponce reefs affected by terrigenous sediments showed decreased coral cover, lower species diversity, and a shallower lower limit of coral growth compared to La Parguera reefs.

Figure 4. Changes in total coral cover, cover by species, and percent fine terrigenous sediment between stations.



The depth to the which living coral can be found is directly related to clarity of the water column. At the Parguera shelf edge living coral was observed past 70 meters. No living coral was observed below 32 meters at Ratones and at Bajo Tasmanian no coral was found below 18 meters. The lower limit of living coral at Cayo Cardona was 12 meters. The shelf edge reefs at Peñuelas and La Parguera were relatively free of terrigenous sedimentation; species richness and coral cover values compared favorably with other Caribbean reefs.

The most striking and important effect of the terrigenous sediment influx is the increased turbidity and loss of light, which results in a shifting of the zonation and an upward migration of zone depths (Hallock & Schlager 1986). Loss of light is critical to the deeper coral assemblages, and a chronic increase in turbidity will move the lower limit of coral growth to much shallower depths. This is reflected by a marked change in the reef front zonation with depth. A compression of the depth zonation is accompanied by changes in coral species domination which is directly related to species tolerances for sediment stress. Reef zonation and variations in coral diversity appear to be a response to natural and man influenced stresses and energy inputs. Deeper parts of reefs with high sediment influx showed reduced species diversity and cover (Table 3). Light reduction is a major impact resulting from excess sedimentation and both loss in total coral cover and a shift to slower growing coral species were seen. Comparison of the changes at Cardona, Bajo Tasmanian, and Ratones to the deeper levels at Peñuelas and La Parguera also showed an absence of many species that normally extend to depths of 25 or 30 meters. Continued stress has reduced the cover from the original 30 to 40 percent cover to less than 3 percent and the number of species from more than 20 to less than 5. The reefs with high sediment inputs showed decreased coral species diversity and percent cover. Other effects from sediment influx commonly seen were: partial or total burial of coral colonies, bleaching and colonization of the coral surfaces by filamentous blue-green algae. The reduced light levels resulted in domination of the community by deeper forereef coral species.

Table 3. Total Coral cover and Number of Coral Species.

Depth in meters	5	10	15	20	25	30
Sites			% total cover			
Parguera & Peñuelas	16	23	23	30	35	25
Ratones	6	10	13	7	5	.1
Cardona	.1	4	0	-	-	-
Bajo Tasmanian	-	6	3	-	-	-
Sites			number of species			
Parguera shelf edge	13	18	17	21	20	19
Ratones	9	14	13	11	7	2
Cardona	3	9	0	-	-	-
Bajo Tasmanian	-	12	11	-	-	-

Problems of increased nutrient levels can also be a problem for coral reef survival. Increased nutrients cause increases in plankton population which further reduces the light levels; increased nutrients will also promote growth of algae which compete with coral for the available substrate space.

Although corals do not account for the major fraction of total reef community biomass when they die (Table 4), the community degenerates and soon the associated reef fauna either dies or emigrates, thus the resistance of this community to environmental stresses cannot exceed those of its coral components (Morelock et al. 1979). Recuperation is improbable because once corals die, their surfaces are rapidly colonized by filamentous algae, making it impossible for coral larvae to settle (Cresher 1969b). The ecological conditions that follow the loss of a reef may be so different that those which existed when the reef community developed, that recolonization may be impossible. Observation of reefs at Guayanilla for the past 10 years show almost no skeletal growth and no evidence of recolonization (Morelock pers. obs.). The response of coral communities to anthropogenic activities is poorly understood, the information available on the tolerance and effects of outside stresses on reef corals are important for developing guidelines for their conservation.

Table 4. Bottom cover coral and other organisms of four square meter quadrants (modified from Szmalts-Forelich 1972).

	Station upper *Acropora*	Lower *Acropora*	buttress top	reef slope
Gorgonian	3.5	7.0	5.0	6.8
Erythropodium	2.5	14.0	0.3	2.8
Palythoa	0	5.5	21.2	0
Millepora	0	4.1	15.8	0.5
Sponges	0	0	18.8	0
Acropora palmata	30.7	3.2	1.2	0
A. cervicornis	0	0	0	7.0
Porites asteroides	2.2	7.9	0	4.5
Siderastrea ssp.	0	0	0	11.0
Montastrea ssp.	0	7.6	0	3.0
Diploria ssp.	0	5.3	0	12.0
Agaricia agaricites	1.2	0	0	2.0
Isophyllia	0	0	0	0.5
Favia fragum	0.3	0	0	0

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